Tropical Cyclone Structure and Intensity Change

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LONG-TERM GOALS

The long-term goals of this research are to understand the nature of the interactions between a tropical cyclone and its larger scale environment, and the impact of these interactions on tropical cyclone structure and intensity.

OBJECTIVES

The primary objectives during the last year have been: (1) To understand the effects of vertical wind shear on tropical cyclone structure and (2) To understand the roles of the Madden-Julian Oscillation (MJO) and westward-moving waves in the occurrence of outbreaks of tropical cyclones in the western Pacific.

APPROACH

The first objective makes use of cloud-to-ground lightning data obtained from the ground-based National Lightning Detection Network (NLDN) and gridded analyses from the European Center for Medium-Range Weather Forecasting (ECMWF). The lightning data was composited with respect to the tropical cyclone centers, and rotated azimuthally in order to examine its distribution with respect to the vertical wind shear vector. All tropical cyclones within range of the NLDN between 1985 and 1999 were included.

The second objective made use of gridded analyses from ECMWF and of outgoing longwave radiation (OLR) data. Both data sets were filtered in time to isolate the slowly-varying background (periods greater than 20 days) from the time scale of waves and tropical cyclones. In addition, numerical modelling work has begun. Initially, this work has made use of a shallow water model to give insight into how the Madden-Julian Oscillation, mixed Rossby-gravity waves, and tropical cyclogenesis might be related.

WORK COMPLETED

A paper by former PhD student Michael Dickinson and Molinari was published by *Monthly Weather Review* in November 2000, entitled "Climatology of Sign Reversals of the Meridional Potential Vorticity Gradient over Africa and Australia".

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14. ABSTRACT
The long-term goals of this research are to understand the nature of the interactions between a tropical cyclone and its larger scale environment, and the impact of these interactions on tropical cyclone structure and intensity.

15. SUBJECT TERMS

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Michael Dickinson completed his dissertation entitled "Influence of Large-Scale Inhomogeneities on Tropical Wave Growth and Subsequent Tropical Cyclogenesis".

Dickinson and Molinari submitted a paper to *Journal of the Atmospheric Sciences* entitled "Mixed Rossby-gravity waves and western Pacific tropical cyclogenesis. Part I: Synoptic Evolution".

A paper was accepted by *Monthly Weather Review*, authored by former PhD student Deborah Hanley, Molinari, and Daniel Keyser, entitled "A composite study of the interactions between tropical cyclones and upper-tropospheric troughs". It will appear in the October 2001 issue of the journal.

Two papers were published by Molinari and his students in *Monthly Weather Review*. The first was "Origins and Mechanisms of Eastern Pacific Tropical Cyclogenesis: A Case Study", and the second was "Planetary and Synoptic Scale Influences on Eastern Pacific Tropical Cyclogenesis". Both appeared in 2000.

A paper was submitted to *Monthly Weather Review* by PhD student Kristen Corbosiero and Molinari entitled "The effects of vertical wind shear on the distribution of convection in tropical cyclones". A second paper entitled "Relationships between storm motion, vertical wind shear, and convective asymmetries in tropical cyclones" is nearly completed.

PhD student Anantha Aiyyer has completed several simulations of the growth of precursor disturbances to tropical cyclones in the western Pacific. His simulations have shed light on the results of Dickinson and Molinari mentioned earlier.

RESULTS

The papers by Dickinson and Molinari (2000), Hanley et al. (2001), and Molinari et al. (2000a,b) were presented in last year's report and will not be discussed here.

Dickinson's thesis showed that variations in the large-scale dynamical environment played a major role in the evolution of pre-tropical cyclone disturbances. The largest impact came from the presence of the active phase of the MJO. Dickinson showed that the MJO alters the environment in such a way as to encourage wave accumulation, mean-to-eddy kinetic energy conversion, and unstable (modal) growth of disturbances. Multiple outbreaks of tropical cyclones can occur in these environments over a relatively short period of time.

Dickinson and Molinari (2001, submitted) showed the most dramatic example of the above: a five-week period dominated by two features: the active MJO, and a very large amplitude mixed Rossby-gravity wave packet. Three tropical cyclones formed in the vicinity of 10N, 145E, each within a separate counterclockwise gyre associated with the wave packet. The latter formed within the envelope of the active MJO. As the MJO moved eastward away from the region, the wave packet dispersed and no additional tropical cyclones formed.

PhD student Anantha Aiyyer has taken the philosophy of using a simple shallow-water model to simulate lower-tropospheric evolution, but with background states either taken directly from observations, or based closely on observations. The slowly-varying background with an active MJO is simulated by integrating to steady-state with an imposed mass sink. Linear model simulations with small-amplitude disturbances are carried out with this background state assumed fixed. Analyticallydefined mixed Rossby gravity wave trains are generated and interact with the background state. Aiyyer has shown that off-equatorial growth of disturbance vorticity occurs as the waves interact with the MJO. The process strongly resembles wave accumulation, though we have not yet confirmed it. This work will continue as part of Aiyyer's PhD.

The first paper by Corbosiero and Molinari (2001) shows the dominant influence of vertical wind shear on the asymmetric structure of convection in tropical cyclones. The downshear maximum in convection is persistent for almost all magnitudes of vertical wind shear, even less than 5 m s^{-1}. The maximum shifts slightly left of downshear within 100 km of the center, and is clearly right of downshear beyond the 100 km radius. The latter signature is the "stationary band complex" of Willoughby et al. (1984), also known as the "rain shield" (Senn and Hiser, 1959). Two examples of this structure are shown in Figures 1a,b. Figure 1a shows the lightning distribution with respect to the moving center in a tropical storm over land (Alberto, 1994). Figure 1b shows the same fields in a hurricane over water (Bertha, 1996). Each figure covers a 72-hour period in which all flashes have been rotated according to the varying vertical wind shear vector over the period. The overall flash rate is lower in the hurricane, and the radial distribution shows a sharp minimum outside the eyewall in the hurricane but not in the tropical storm. The reasons for this structure are discussed in detail by Molinari et al. (1994, 1999). Of primary interest in Figures 1a,b are the strikingly similar *azimuthal* distributions of convection with respect to the vertical wind shear vector. The large majority of flashes within 100 km of the center occur downshear and downshear left, while the majority of flashes in the outer rainband region occur downshear right. The inner maxima tend to be quasi-circular, while the outer maxima are banded. It is notable that this similar azimuthal distribution of convection occurs in two storms that differ in intensity, in the magnitude of vertical shear, and even in their underlying surface.

IMPACT/APPLICATIONS

Considerable controversy exists with regard to the role of traditional easterly waves in cyclogenesis in the western Pacific. Several papers exist in the literature (e.g., Sobel and Bretherton, 1999) that argue in favor of accumulation of Rossby-type waves as pre-cursors to tropical cyclogenesis, yet other authors (see review by McBride, 1995) argue that such waves play almost no role in the western Pacific. Our work provides a third alternative: that mixed Rossby-gravity waves, which are like easterly waves in that they move westward and produce off-equatorial convection, can be pre-cursors to tropical cyclones. It has also been argued that n=1 equatorial Rossby waves can also be seedlings for tropical cyclones (Ferreira et al. 1996). We believe that much more attention needs to be paid to these equatorial modes and their interaction with the MJO in order to understand tropical cyclones in the western Pacific in Northern Hemisphere summer and fall.

A number of papers in the literature deal with idealized models of tropical cyclones in shear (e.g., Frank and Ritchie, 2001), but only two observational studies have been published (Franklin et al. 1993; Reasor et al. 2000). The first paper by Corbosiero and Molinari provides considerable observational support for the simulations of Frank and Ritchie (2001). The second paper by Corbosiero and Molinari will argue that the well-known effects of motion (which are reproduced in the study) are in fact an artifact of the strong relationship between tropical cyclone motion and vertical wind shear.

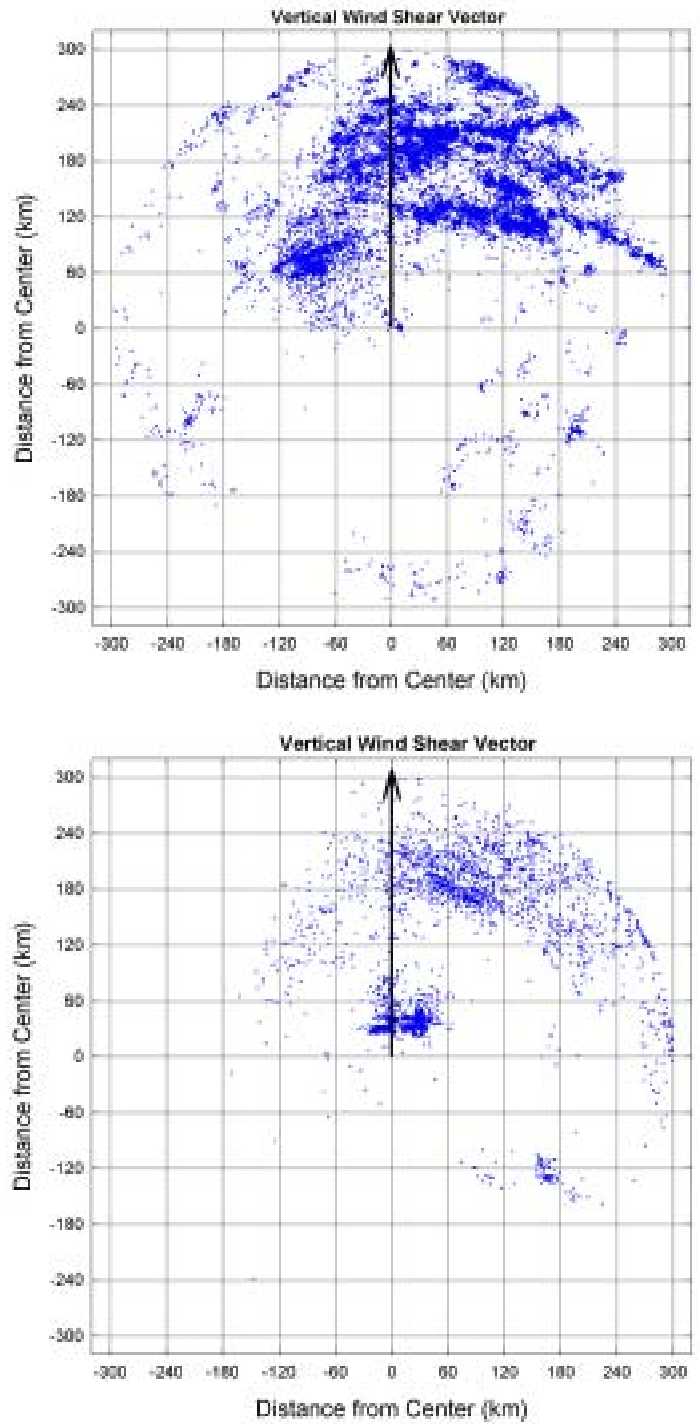

Figure 1. Locations of cloud-to-ground lightning flashes (dots) within 300 km of the center of (a) Hurricane Bertha (1996); and (b) Tropical Storm Alberto (1994). Each flash location has been rotated with respect to the varying vertical wind shear vector over a 72-hour period for each storm. The results show a downshear maximum in lightning in the storm core, and a downshear right maximum in the outer bands.

TRANSITIONS

The longer the lead time needed in tropical cyclone forecasts, the more important it becomes to account for tropical cyclogenesis. A full-fledged tropical cyclone can easily form within 5 days. Knowledge of repeated tropical cyclogenesis in the same region is potentially quite valuable. The work by Dickinson shows one set of circumstances that produce multiple storms: an active MJO and associated growth of a Rossby-gravity wave packet. Future work will examine how commonly such events occur.

The work of Corbosiero and Molinari suggests that tropical cyclone structure is overwhelmingly dominated by vertical wind shear. The vertical wind shear is reasonably well forecast by operational numerical models, and we believe it will be possible to accurately forecast the most dangerous quadrants of storms for shipping well in advance.

RELATED PROJECTS

We are conducting a study under NSF support of easterly wave dynamics in the Atlantic. We are investigating the structure and dynamics of the hurricane core under NASA support, and the amount and distribution of rainfall in hurricanes after landfall in a project funded jointly with Professor Lance Bosart of my department.

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ABSTRACTS AND OTHER PUBLICATIONS

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All of the work is done at the University at Albany, State University of New York.